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ABSTRACT

This chapter presents some ways to reorganize science and mathematics education guided by a wisely chosen, strategic, and secure research base. Needs for systemic reform, educational equity and quality as complementary goals, and urgent and strategic investment in research are discussed. Targets for new research and development are also identified including vignettes on learning core ideas, reforming the gatekeeper courses, reform at secondary and postsecondary levels, new curricula and implementation strategies, school restructuring, assessment pools, and effective models for teachers' professional growth. Finally, territories for research on systemic reform are suggested which include technology education, statistical data management, and agriscience; interdisciplinary inquiry; discourse analysis and networking; new technologies; and methodologies. (KHR)

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5 Improving Research and Systemic Reform Toward Equity and Quality

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The reform of mathematics and science education in the United States has become a national priority, but teaching improved content in these subjects successfully to the majority of students is in jeopardy. As federal, state, and local agencies commit to improving the performance of our students in mathematics and science, they must come to terms with the extent of the problems first. The situation resembles this one. Imagine cranking the handle of a well and finding a very leaky bucket. Along comes an official who asks, "Who is responsible for this intolerably leaky bucket?" The subsequent questions are: Will the responsibility for the condition of the bucket be placed with those who left it too long without attention and care? Those who actively poked holes in it? Those who used it and ignored the leak? Or those who lifted the bucket up and let the state of disorder and neglect become evident to the public? A short-sighted Congress demanding immediate accountability is unlikely to be particularly circumspect, and any agency or political group advocating educational reform aggressively is in the precarious position of being left "holding the bucket," as it were. Added to this is a skeptical scientific community whose funding cuts in research leave some inclined to jettison the unruly and expensive efforts entailed in reforming science and mathematics education. Sadly, too, public debate and controversy are increasing as reformers make it clear that their goal is to educate all children better, not solely the narrower, albeit important, objective of preparing an elite few to become mathematicians or scientists.

In this chapter, I make the fundamental claim that in this unstable but vigorous climate of reform, the reorganization of science and mathematics education needs to be guided by a

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wisely chosen, strategic, and secure research base. Whereas, to this point, research has contributed toward a vision of what reform should look like in the classroom, in terms of curricula, pedagogy, and assessment, what is needed urgently now is a complementary body of research that can support explanations and predictions about the *process* of reform. This call for research leaves investigators with an important choice to make in the relatively young and overtaxed field of research in science, mathematics, and technology education; namely: Should we continue to engage in the types of studies that have created the climate and demand for reform, or should we turn to implementation issues and take on the challenges that the trajectory of reform is creating? Or is there another choice?

I claim that there is another choice and that it lies in the acknowledgment that research never anticipated all of the leaks in the bucket, nor did it bring strongly enough into relief the fact that the bucket is only a small part of a large system. It is undeniable that researchers identified critical issues. We identified the importance of the active involvement of students in constructing their knowledge (Confrey, 1994b; R. Glaser & Silver, 1994; Steffe, 1995; Tobin, 1993), documented the negative impact of unaligned assessment systems (with problem solving or conceptual thinking; Lesh & Lamon, 1992), harnessed the power of new forms of semiotics using new technologies, and described the character and intensity of successful professional development (Schifter, 1996a, 1996b; Schifter & Fosnot, 1993). Despite the importance of these results, changing any one of them alone was proving insufficient to fix the problems of mathematics and science. Carrying the analogy one step further, the preferred solution may lie not only in replacing or repairing the bucket, but also in selecting different water sources, redesigning the crank, moving the well, or building a reservoir and pumping station.

The fact is that the results of research must be implemented in the educational system. If the system is not prepared to change, then identifying the problems will not lead in any direct fashion to solutions. For instance, consider these examples: Learning to listen equitably to all students will not eliminate policies that systematically lead to the disappearance of some underrepresented groups in the upper division, thus denying them equal opportunity; designing new assessment systems will not tell schools how to respond to parental outcry about new forms of report cards; and introducing new semiotics will not prepare textbook publishers to produce electronic or multimedia materials automatically. All of these changes

require one to look more broadly, beyond the restricted focus of a research study. All of them require us to move beyond the level of the classroom, a move that occurs only rarely in educational research. Briefly, the problems in mathematics, science, and technology education are systemic and, thus, require a systemwide intervention strategy.

THREE PREMISES

Premise 1: A Need for Systemic Reform

Therefore, I begin with the premise that some type of *systemic reform*[1] is needed. Let us define this term at the outset. Systemic reform is a phrase that melds the concepts of systems and change and, accordingly, refers to processes of continuous examination, feedback, and improvement in organizational systems that are working toward providing high-quality science, mathematics, and technology education to all children. Such systems include an array of interested parties (teachers, students, parents, administrators, professors, business people, taxpayers, volunteers, service providers, etc.) at multiple organizational levels who converge to work toward the goal of high academic performance by all students in science and mathematics. Reform efforts must acknowledge that instructional systems generate feedback, impetus, resistance, and controversy—issues of specific interest in systemic research, but ignored in much existing research. The complexity and natural diversity of such systems must be addressed realistically if decision making is to support positive and enduring change.

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[1] I have comments in this chapter that are reflections of my experiences with the systemic reform programs of the National Science Foundation's Directorate of Education and Human Resources. Over the last few years, I have served on numerous panels, technical assistance teams, and discussion groups in these programmatic efforts. All comments in this chapter are my own responsibility, but many benefited from numerous discussions with members of these communities.

When undertaking research in systemic reform, we must keep in mind that the number of people involved in education is second in number to the health professions, and that researchers are a tiny but critical fraction of the educational field. In education, we are working with what Heinz von Foerester (1982) called a "principally undecidable system," too complex in its feedback cycles to be modeled causally, but nonetheless improvable by an iterative design process. This suggests that instead of viewing research as establishing universal principles for learning or teaching, it could be conceived of more productively as meeting design challenges. If this were the case, then the bulk of educational research must change to be more like engineering research, with targeted goals, explicit deliverables, prototyping, iterative design, and direct and widespread field testing in existing programs of reform.

Because systemic reform is being carried out widely already, we are dangerously behind on guiding, assessing, and modeling this process carefully and systematically. Even if we import a semiengineering approach, we also must attend directly to the fact that most of our colleagues in science and mathematics are trained to evaluate research according to scientific and mathematical standards, not the standards of social science. Thus, when the Mathematical Sciences Education Board of the National Academy of Sciences worked to produce a document linking research to reform, its members (I was one of them) struggled mightily over the question of what counts as evidence. This is not to deny that we need to insist on clear standards of evidence in social science and to recognize the need to include both qualitative and quantitative measures, but we also need to realize that one primary goal of social science research is to guide informed decision making. Unlike the claims of many in science, evidence does not provide us universal solutions, but it does permit us to find better ways to envision our work, lead the development of improved products, describe the conditions under which effective solutions have thrived and so on. Social science is unapologetically value-laden (see Confrey & Lachance, chap. 10, this volume); consequently, research results should be debated and interpreted. This is not a failure of the system but a strength. We can document, make careful argument, link theory with practice, evaluate, and, importantly to note, guide the careful design of programs and products.

Research is critical to achieving an informed vision of how to proceed. To do this, researchers must acknowledge more widely the role of research in our current understanding

of the directions for reform and strengthen intentionally its connections to the overall system in which education is practiced. With regard to the role of research, I point out briefly that much of the basis of the standards for mathematics (National Council of Teachers of Mathematics, 1989), and for science (National Research Council, 1996) came out of the research base on children's learning. It was early research on the inadequacy of standardized tests and, subsequently, on children's conceptions that fostered the constructivist approach, group learning, and the role of reflection and communication. That this is poorly acknowledged by the authors has been useful in making the standards populist documents, politically strategic but unfortunate and inaccurate in relation to research. Although many of us in research recognize that it could and should be more influential in its impact on practice, I submit that its fundamental contributions to the teaching, learning, curricular, and pedagogical parts of the new approaches to science and mathematics education need to be acknowledged more extensively too.

To increase its influence, research can respond to the issues that are evolving from systemic reform and continuing to generate new and inventive ideas. Education is inherently a practice, and, as such, research must be linked closely to this practice, but that term should be defined broadly. For instance, research on the application of new technologies to education may not find its link in typical school practices but may relate first to the practices of scientists and mathematicians, financiers and architects, computer scientists and engineers working in the field, solving complex problems (Hall & R. Stevens, 1995, 1996; M. Resnick & Ocko, 1991; Wilensky, 1995). However, informed by the actual activities and tools of these professionals, researchers must create quickly the bridges into classroom activities and tie to children's ways of thinking and acting as well as to school-level accessibility to technological tools.

Thus, I suggest that research directions could be changed to guide and support reform more effectively by identifying fruitful and strategic topics for investigation, the results of which will advise existing systemic reform and direct future efforts, and by finding ways to make the research itself more systemic. When considering topics, we should conduct research on systemic reform too (Chubin, in press; O'Day & M. Smith, 1993; Porter, Archbald, & Tyree, 1991). Most of the remainder of this chapter is devoted to discussing some suggested research targets. However, I also claim that it is essential for research to be viewed as a part of

systemic reform, not separate from it. Accordingly, we need, as a community, to define what it would mean to make research itself function more systemically. By conceptualizing research more systemically and by linking it more closely to systemic projects, the research is likely to lead to increasingly diverse, challenging, and rigorous theories, methods, and questions.

Premise 2: Equity and Quality as Complementary Goals

Before discussing equity and quality, I suggest two basic principles that must underlie even more fully all calls for research and that should guide the selection of priorities. The first concerns the relationship between equity and quality. Most people advocate for both of them as overarching principles, but of crucial importance is clarification of the relationship between them (Confrey, 1995a).

Too many people in mathematics and science education see equity and quality as competing, and not complementary, goals. Too many of the underemployed or underfunded scientists and mathematicians in this country view themselves as victims of social engineering programs designed to force equity on them at the cost of quality. Instead, it would be helpful if they understood that one cause of their state of underemployment, is the failure to educate a broader base of the citizenry who understand the importance of their work and see its pursuit as in their own interests. Likewise, the reform of mathematics and science education is facing the immediate challenge of the pursuit of equity and quality being viewed by some very influential people as divergent paths. To obtain equity, they fear the loss of a quality education for their children and, therefore, are understandably unwilling to pay the price. To others, the system has underserved them repeatedly, and they believe that neither equity nor quality are likely to be provided them or their children. Without addressing these beliefs, the satisfactory reform of mathematics and science education will remain in serious jeopardy.

In biological terms, it is as if we believed that evolutionary success and biodiversity were incompatible and that we adhered to a naive belief that survival and dominance of the fittest were the ultimate criteria for achievement. To counter such views, we must educate the public to comprehend that the number of survivors is only one measure of evolutionary success and that being adaptive to a changing environment is a far superior, evolutionary trait. Symbiosis, commensalism, and mutualism are all forms of cross-species cooperation on which survival depends, and they are obligatory for all parties, not only for survival but also for enhancing

the quality of that survival. To obtain a competitive advantage, one must know what one is competing against, and, in the current educational conflicts, one wonders if the correct threat is being identified and answered. For instance, in our culture when dropping tracking leads to community crisis and dispute, although the lack of decent technologies in virtually any school is seldom acknowledged, one must ask if, perhaps, the wrong source of competition has been identified.

Reform efforts must be dedicated to demonstrating that both equity and quality are the rights of all of the citizens in our country and that they can be achieved only in tandem. For reform to be successful, all of its participants must seek aggressively to uncover, clarify, and challenge the view that to achieve or protect quality, the price must be equity. Reform must differentiate between *expertise* in mathematics and science and *elitism*, and make expertise an accessible goal for all citizens. Primarily through their efforts in research and systemic reform, researchers and practitioners must lead the country in a courageous stance on these issues, largely by insisting that funding decisions and the continued support of systemic reform value equity, demand quality, and, therefore, are based on merit and not entitlement.

Specific research goals should include investing in inquiries that will clarify the relationship between equity and quality, both philosophically and empirically, and developing more sensitive measures of outcome and participation to ensure that equity considerations are not reduced to the mere counting of participants' ethnicity, gender, age, or class (Darling-Hammond, 1992; Tate, 1995a, 1995b).

Premise 3: A Situation of Urgency and Strategy

In addition to my commitments to systemic reform, equity, and quality, I add a third premise: that we are working in a situation of urgency. This urgency is created by the basic rate of change being experienced in the world today. We are racing toward a global community where, for example, a five-person, senior, editorial staff for a new journal, the *International Journal of Computers for Mathematics Learning*, sits on three continents and communicates daily about acceptances and schedules; a precarious environment struggles to sustain the demands heaped on it; and an intertwined international economy operates in which the United States must participate both competitively and collaboratively. Add to this the increasing economic disparity in this country between its most and least wealthy, and one sees an educational system under significant pressure to maintain its democratic ideals.

As a result, the investment in research must be strategic. To be strategic, research should be viewed as an interactive design process, during which conditions and constraints are identified, aggressive field testing is done, and close attention is paid to market conditions. The outcomes of research should be identified explicitly, and the pathways to widespread dissemination should be built into the system. Means of identifying mutual problems and defining them as strategically accomplishable tasks need to be institutionalized.

SPECIFIC TARGETS FOR RESEARCH ON SYSTEMIC REFORM

After reviewing a number of systemic programs, one becomes aware of certain issues that haunt the reform process repeatedly. I identify in the following list specific targets for new research and development. In order to decide how to address these targets, it can be helpful to consider them in light of what the National Science Foundation's (NSF) Division on Education and Systemic Reform calls the "drivers" of systemic reform (NSF, 1996). The term *driver* is used to suggest that how this component is carried out determines whether the overall program has impetus; like a mechanical driver, it is the interlinking of the "gears" that gives the systemic program its force. The six drivers are:

- Standards-based content, curricula, pedagogy, assessment, and professional development.
- Policies to support and enforce standards-based instruction.
- A convergence of resources to support the first driver.
- Broad-based partnerships that include public awareness, community involvement, and private enterprises.
- High-quality and multiple-outcome measures.
- Data analysis to examine the equity of the outcomes.

If we wish to achieve our equity goals, we must report the disaggregated outcomes of achievement gains obtained by both traditional and novel assessments, beginning in kindergarten. One logical way to eliminate a gap in performance between such groups as Whites, Asians, and students of high socioeconomic status in relation to African Americans, Hispanics, and students of low socioeconomic status is by halting our contributions to that gap in the early grades.

The drivers can assist us in proposing research approaches to the targets and the new territories identified in the next sections. As one proposes a research approach to a problem, one should consider how each of the six drivers relates to it and broaden one's approach to view them as covarying factors.

Target 1: Vignettes on Learning Core Ideas

The heart of schooling lies in the interactions among teaching, learning, curricula, pedagogy, and assessment, and the bulk of the research needed lies in attaining improvements in everyday classroom activity (Ball, 1993a; Piliero, 1994). Systemic reform has made the linking of these components of education a possible target of reform such that if interventions fail to improve their interactions, we will have accomplished little of direct benefit to children. Research has made the most progress in the area of learning, where numerous typical conceptions and conceptual challenges have been identified (Confrey, 1990). In some areas, much investigation has been done—physics, certain biological processes, early number, ratio and proportion, basic probability, geometry, and functions—whereas in others virtually none has been done—trigonometry, algebraic structures, engineering education, chemistry, and agriscience.

By now, we should have examples of students working on interesting tasks, at grade level, so that teachers can access them systematically, watch videotaped interactions with children of diverse backgrounds, and reconsider the content in light of the result. Subsequently, teachers will be able to instruct with better depth of content and more sensitivity to their students. These examples should deal with core ideas, and they should be curricularly specific while avoiding being curricularly diosyncratic dependent. A strategic target would be the creation of a centralized repository of examples of students' approaches edited carefully, replete with students' work, and make it accessible to practicing teacher-educators and schools. The examples should illustrate not only students' typical approaches, but also the fertile possibilities that they raise, the challenges that children are deemed capable of meeting, and sociocultural views of what mathematics and science are, acknowledging diverse processes and perspectives. This repository should be expanded by adding additional samples and soliciting research on topics that have been neglected. Research on the impact on professional development of making such resources systematic and available, teachers'

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knowledge of content, and effective and inclusive pedagogy should follow. The use of new technologies, multimedia and the Internet, for example, should be exploited in this process.

We still need to focus on issues of learning, but place that focus in an interactional framework among learners and teachers. To do this, we must conduct more transformative teaching experiments (see Confrey and Lachance, chap. 10, this volume). These should be longitudinal experiments where we subject our approaches to the everyday constraints of classroom teaching and are explicit and bold about how instruction can be reformed dramatically so that students' learning will improve. Research on efficacy and on motivating achievement demonstrates how essential it is to believe that children can learn (Anderman & Maehr, 1994). After recognizing the importance of this critical element of the equity agenda, teachers also need to master how to make good use of the learning opportunities created by children when they are engaged in interesting tasks. Classroom observations show that teachers frequently miss or obliterate these opportunities repeatedly because they concentrate on narrow conceptualizations of the tasks and their outcomes, seeking premature closure with the goals that they initially set. Consequently, children's "wonderful ideas" (Duckworth, 1987) get overridden or ignored. This is the result of such problems as insufficient or, too often in the case of secondary and postsecondary teachers, inflexible knowledge of the subject matter, failure to engage students in motivating tasks, lack of belief in students' capacity, an overburdened curriculum, and/or an accountability in assessment systems that reward superficial behaviors.

To meet this goal, we need to create a number of longitudinal test-beds or field-sites for reform. The engagement with the staffs at the sites should be as a partnership where the joint modification and revisioning of approaches is studied and documented simultaneously with the creation of the extended vignettes.

Target 2: Reforming the "Gatekeeper" Courses

Research on learning, teaching, and pedagogy should concentrate on whether the investments made in reforming the "gatekeeper" courses such as algebra and calculus (entry-level courses that students must pass in order to be able to progress onward) are achieving their desired outcomes in terms of equity and quality. Documentation of the extent of the reform needs to accompany careful descriptions of the changes in what happens in classes and to assess their impact. Increasingly, we need to be certain that the algebra we substitute is an intellectually

powerful one, not merely the manipulation of symbols, but the application of quantitative reasoning and modeling to interesting and important phenomena. Of fundamental concern is to ensure that all schools and students have access to the most recent advances from research on learning about functions and relations, efficient algebraic manipulations, the revitalized role of geometry, and the use of appropriate technologies.

Target 3: Reform at Secondary and Postsecondary Levels

Reform in algebra at the middle or early high school levels will necessitate a much stronger intervention into reform at the upper levels. There is some evidence that this will not follow automatically from reform in the elementary and middle grades. That reform in high school is stalling is due largely to the tendency of high school teachers and parents to look to the universities and colleges for guidance. How can we advocate for dramatic restructuring at the kindergarten through Grade 8 levels without assuring ourselves that high school and university expectations and experiences will be realigned suitably? Across the country, only the Montana State Systemic program (SIMMS) has begun by reforming secondary mathematics courses; then has attempted to work back down the system to align mathematics instruction from kindergarten through Grade 8. Another approach to secondary reform that shows potential promise is the idea of vertical teaming, both among elementary, middle, and secondary schools and between high schools and community colleges, colleges, and/or universities (UCAN Rural Systemic Initiative).

Effectiveness of vertical teaming between high school and university faculties can be restricted because of students' mobility. However, in many regions, such mobility is limited, and large numbers of students advance to local community colleges, colleges, or state universities. This is particularly the case as the cost of higher education increases. Exploring these kinds of local collaborations can suggest ways to escalate reform in the upper grades.

Target 4: New Curricula and Implementation Strategies

A constructivist approach assumes that children are being given interesting and challenging curricular tasks to work with. We need to know to what extent this is happening and to foster its growth (Ferrini-Mundy & M. A. Clements, 1994; Raizen & Britton, 1996–1997; Silver & Cai, 1996). Two research areas can assist here: funding attempts to build on, modify, strengthen, and evaluate the curricular innovations of the last 6 years and studying the

strengthen, and evaluate the curricular innovations of the last 6 years and studying the implementation models that work. The NSF's work to develop alternative curricula has led to stronger curricula (although most of them were dated technologically by the time they were published because of rapid changes).

Also, a number of schools are trying implementation strategies such as replacement units, cluster approaches, or schoolwide reform. Replacement units, where a teacher commits to a 2 to 6 week experiment using a particular part of a novel curriculum, are an interesting strategy because they focus multiple teachers' attention on the same event; they are a manageable amount of change for most teachers, even reluctant ones; and they can lead stepwise toward deep and lasting reform.

We need to identify and study these implementation strategies systemically. How do they interface with state mandates? Do they reach the unwilling or uneasy teachers? Are there hooks to accountability? How are publishers responding? Is the penetration as deep in different settings (rural, suburban, and urban), regions, and grade levels? What are the professional development implications of these approaches? Is curricularly dependent professional development a useful model? What are the trade-offs between depth of implementation and the pressure to increase the scale of activity?

Target 5: School Restructuring

Having recently completed 8 weeks of work introducing algebra through ratio and proportion, the use of motion detectors, and multirepresentational software to all of the students in seventh grade, I can attest to the fact that the limited length of the class period was the greatest deterrent to reform. Teachers' doubts that students could tackle challenging problems in the class time allotted were reaffirmed as 42-minute periods made high-quality intellectual pursuit a race against the clock. When we began this endeavor, we were told that it would take 3 years to restructure class times in order to arrange for back-to-back mathematics, science, or technology periods. This kind of temporal inflexibility is a major impediment to reform. In restructuring, we also need to investigate such factors as the feasibility of hiring mathematics and science specialists in the upper elementary grades. With changes in the use of Chapter 1 funds, there are pivotal opportunities to reorganize the deployment of school personnel to assure that all children receive high-quality mathematics and science instruction.

Target 6: Assessment Pools

We need to implement a strategic plan for assessment so that researchers can contribute to systemic reform from this area too. At least two states (Arizona and California) have experienced serious setbacks as political change in the state derailed statewide assessment programs that were designed to be more aligned with reform. Furthermore, at the assessment meeting of the NSF Urban Systemic Initiatives in 1996, there was a clear call for a pool of assessment items that are semi-open-ended. The practitioners indicated that they needed an easy way to acquire such items and tailor them to their local contexts, while still asserting stamps of validity and approval for them. This is an attainable target for researchers who could provide such approval, and it suggests a collaborative effort of researchers, practitioners, technical assistance teams, private corporations, and professional organizations. In its design, we need to consider how to expand such a system after its initial development. Assessment instruments that include the expertise and active participation of local teachers are sure means of strengthening reform. In addition, local school districts not only must be held strictly accountable for the educational systems over which they exercise control, but also they must accept national guidance.

Target 7: Effective Models for Teachers' Professional Growth.

To my mind, developing effective approaches to teachers' professional growth is the thorniest and most troublesome challenge in reforming education because classroom teachers are the key to good instruction. There is evidence that we continue in a downward spiral here, with teachers less well prepared to teach in a world in which more and more mathematical, technical, and scientific knowledge is demanded (U.S. Department of Education, 1996). Two-hour or one-day workshops on trendy topics still dominate professional programs, and when given opportunities to engage in intellectually challenging professional development, too many teachers shy away. Furthermore, much of what is provided in teachers' preparation programs or inservice training is weak, poorly informed by research or content expertise, and only minimally connected to classroom practices. Even when teachers are given strong in-service activities, frequently they are under no obligation to implement the methods in their classes, and school pressures make it difficult for even the staunchest reformers to persist.

Moreover, site-based management teams who often are charged with identifying and planning professional development directions typically fail to be well enough informed on the opportunities and possibilities in science and mathematics education. We desperately need research to identify professional development models that work well. Nationally, we have moved from approach to approach in an attempt to identify the ones that are successful: teacher-leaders, teachers' collaboratives, action research, site-based management teams, and community- or school-based interventions (National Institute for Science Education, 1996). Systemic reform has added cluster approaches, networking, vertical alignment, and regional centers to the mix. To date, there is no clear evidence of which of these approaches are the most effective.

Research on teachers' education has seldom taken a systemic approach. However, it has demonstrated convincingly that teachers find case studies of other teachers undergoing professional changes leading toward reform influential sources for their own learning. Many are motivated deeply by discovering the consistency and persuasiveness of students' methods of learning. When this leads them to need to reconceptualize their own understandings, many admit to feelings of uneasiness, defensiveness, and reluctance to acknowledge and address their inadequate knowledge of the subject matter. This leaves professional development in systemic reform in a quandary. In a system in which participation in specific kinds of inservice training usually is not mandated and in which its professionals are reluctant or scared to address their inadequacies, how does one move a reform agenda forward?

Some answers to this quandary suggest that enabling teachers to change can be accomplished most readily in ecologically embedded settings of real classroom practices, real students, and real curricula—elements that they define as central to their profession. Multiyear summer programs of 2 weeks' or more duration, with follow-up classroom observations, seem reasonably effective. When teams of teachers from the same school participate in such activities, change can accelerate.

Early results from systemic reform suggest that teachers' professional relationships to the educational system need to be reconceptualized. Top-down mandates, poorly informed by the constraints of everyday teaching, inadequately planned, and likely to last no longer than the school year, are met with teachers' understandable skepticism and make them conservative about changing their instructional methods. Thus, effective reform leaders must partner with

teachers to define the necessity to change and provide them support, incentives, and rewards to do so, while simultaneously enforcing policies to remediate, remove, or penalize those teachers whose instructional practices are detrimental to children's intellectual development.

Besides giving teachers adequate education and materials, achieving improvements in their professional development means changing the accountability in the system. Systemic reform permits accountability to be focused clearly toward the realization of measurably improved and equitable outcomes for all students. Accountability, then, must be a reciprocal process of convincing all of the interest groups that students are well served and that people are held responsible for negative results over which they can be fairly expected to exert some control. Recertification for teachers, steps for professional development credit, changes in their employment contracts to 11 months with obligatory summer coursework, and the addition of elementary-level specialists are all means to strengthen teachers' professional development; their effectiveness as strong methods of enforcing improvements must be investigated. The enforcement of anticipated progress must be balanced by providing incentive programs and rewards and recognition for leadership. Furthermore, teachers need assurances that their school principals know how to provide instructional guidance that will respect and facilitate the work of teacher-leaders and experts. If the principals fail to do so, reciprocal accountability means that the teachers need some recourse to ensure that their efforts are not impeded at this level.

In terms of new research, there is an acute need to increase capacity for middle-range professionals by creating viably institutionalized positions linking universities and schools and by guaranteeing continued professional growth and collegial interactions for these talented and dedicated individuals. To stabilize and strengthen reform, research on effective ways of educating and nurturing these professionals and providing them stable employment must occur (Lein, J. Johnson, & Ragland, 1996).

NEW TERRITORIES FOR RESEARCH ON SYSTEMIC REFORM

Just as there are specific targets to suggest for research on systemic reform, there are also new territories for it that are not common yet need to be researched and developed proactively. I would offer five suggestions.

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New Territory 1: Technology Education, Statistical Data Management, and Agriscience

Emerging as important areas in which research can inform us of future directions are technology education and engineering preparation at the middle school level, the management of statistical data, and aspects of agriscience and environmental science. Simultaneously, we need to take a critical and invigorated look at the role of vocational technology courses. As it stands now, in secondary schools, college-bound students are not educated to use their hands, whereas non-college-bound students are not expected to use their intellectual capacity to the fullest. Clearly, both attitudes are problematic, and these traditions ignore the fact that some of the most important, future, scientific and mathematical work will be in new mathematical and scientific fields. The interface between the environment and agricultural practices will be developing. We are seeing employment opportunities with new technologies go unfilled; we will see a similar need developing in applied biology and biotechnology. Mathematicians and statisticians are working feverishly to manage huge, online, real-time data sets. Furthermore, the new technologies are merging scientific, artistic, and visual fields at a rapid pace. If we do not begin to develop curricula in these areas now, we will experience an underprepared workforce. By combining these new field opportunities with a revitalized and systemic approach to career exploration and apprenticeship, we can meet the dual goals of equity and quality.

New Territory 2: Interdisciplinary Inquiry

We are drifting toward increasing interdisciplinary inquiry, and we need to know more about if and how it can be done. Project-based approaches are clearly highly motivating to students and can build conceptual understanding and receptivity to technology if coherence and progressiveness are carefully monitored. However, their success depends on determining what conditions ensure that students are gaining appropriate skills and increased expertise as they proceed through the activities. Careful sequencing of the projects proved key to satisfactory results in my own research (Confrey, 1995a; Lachance, 1996). My research group has had considerable success in implementing a physics-trigonometry course using motion detectors, Interactive Physics©, and Function Probe© in four 9-week units, but it took years to get the curriculum to work, even partnering with highly talented and determined teachers (Doerr,

1994; Noble, Flerlage, & Confrey, 1993). Project-based instruction still requires careful developmental sequencing, practice of skills, mastery of terminology, and control over one's tools. Interdisciplinary inquiry is probably the ultimate direction for curricula, but we must begin to study its development and use now in order to be ready for it (Tinker, 1996a).

New Territory 3: Discourse Analysis and Networking

The analysis of discourse that takes the place during classes continues to offer rich opportunities for understanding quality and equity. New classroom-based methodologies are evolving in which interactions in the classroom are evaluated in terms of both content and process. One promising area is to examine how discourse promotes the development of forms of reasoning and argument (Hicks, 1995; Lehrer, Horvath, & Schauble, 1994). In the 3-year teaching experiment that I conducted with third- to fifth-graders, we saw significant gains in their sophistication of argument and spontaneous roots of proof. Verbal exchange is an important part of securing the foundations of inquiry-based approaches and being sure that they lead to high-quality learning. Discourse analysis is also an excellent way to see how participation patterns and language use can lead to unequal opportunity. Additionally, bilingual instructional settings can help to build a better understanding of the different roles played in conceptual development by different semiotic systems.

New Territory 4: New Technologies

In each of the topics for research proposed earlier, the role of new technologies is an important aspect of the investigation (C. Fisher, Dwyer, & Yocam, 1996; Keitel & Ruthven, 1993). A central research question is: Which technologies used under what conditions lead to smarter users and which lead to only an appearance of expert behavior?

Vygotskian perspectives have established convincingly that the mind and the concept of knowledge are defined in relation to a culture's access to and use of tools, but it is still not clear what technologies and approaches are appropriate for the development of the mind. We must avoid seeing education reduced to technical fluency and schools regulated to teaching outdated and irrelevant skills. We need some skeptical and inventive studies on the uses of new technologies, while continuing our efforts to seek educational applications of advanced technologies and to increase their accessibility and compatibility. More of these studies must take place on site. In mathematics, a researchable question is: What does it mean to be

"rigorous" in a symbol-manipulating environment? In science, we can ask: "What is an appropriate balance between technical facility with complex routines and the planning and interpretation of experiments?

The role of the new technologies as means of communication and of providing equitable access to resources must be researched too. Ideally, the Internet should be accessible easily, but, in reality, gaining access to equipment, getting online, knowing how to move in the system, and representing oneself in it are far from being available equally. Nonetheless, we must continue to develop educational applications of these new technologies and must see them applied to reform. In this arena, practical outcomes, advice to schools on installing networking, and the dissemination of funding opportunities can be centrally facilitated. An interesting potential area for new technologies is to inquire how they can be used in professional development. Multimedia courseware with hooks to the Internet are being developed aggressively by publishers who are investing considerable funds in such endeavors. We could be forging relationships with them to engage in related professional development in exchange for agreements to make these materials accessible for professional growth and researching the potential of such approaches to stimulate change in schools.

New Territory 5: Methodologies

These research challenges are unlikely to be met by using traditional methodologies. They leave one asking the question: How can I produce results if I have to take into account so many different factors? The answer to this question will evolve as the studies evolve, but it will require that we untangle, describe, debate, and refine our approaches to be certain that the methodologies coevolve with our understanding of systemic reform.

MAKING RESEARCH SYSTEMIC

We must begin by admitting that we lack the human resources capacity to make research systemic. If research is not serving our needs as fully as we might wish, it is in part because there are too few of us and we lack diversity. This is a critical problem that can be addressed only with significant changes in how researchers are educated and who is recruited into research in mathematics and science education.

One approach is to connect research to systemic reform through institutional changes. A critically important opportunity to do this is through the technical assistance initiatives associated with systemic reform projects. In helping to identify possible technical assistants for systemic reform, my research group was challenged by the need to locate individuals who were well informed in research and in the resources available, had the practical experience to enter school settings knowledgeably and comfortably, and possessed the necessary cultural and social sensitivities and expertise. Furthermore, effective technical assistance requires credibility, endurance, and trust at the sites where it is given, which means long-term relationships between providers and recipients.

A second intervention is to make use of the rich recruiting grounds provided by current systemic initiatives to find future researchers. However, to do this, one must recruit these potential researchers as students entering graduate institutions that have strong commitments to equity and quality and be sure that their studies do not deter them from, or cause them to develop a disrespect for, school-based practices. If programs to educate such individuals were tied to strategic intervention activities that allowed for reflective study, one would see programs that would serve multiple purposes.

Finally, we must beware of disincentives for the current research community whose commitments to research have helped us to see how to proceed. As universities face budget cuts, grantees face increased pressures to teach more courses, advise more graduate students, and document their worth to their institution to the tiniest detail. Doing research in a more systemic way must not put even more demands on the research community. At present, it is not unusual to expect researchers to identify the problems, propose the possible solutions, carry out the research, disseminate the findings, design the products needed, then seek new funding—and the half-life of a researcher is disturbingly short. Instead, we must organize to allow for high-quality and productive research teams who have stable and long-term funding and to work toward and support profound and lasting reform.

CONCLUSION

Decoupling educational research and reform has perhaps never been so consequential. If systemic reform accelerates away from a research base, it may collapse from the failure to

progress strategically, efficiently, and securely. Such a trajectory is equally dangerous for the research enterprise. Unless researchers contact successfully all of the practices of education in all of their complexity, the research enterprise will be left behind by a systemic reform movement that regards it as increasingly irrelevant and sterile. Both researchers and reformers have much to gain by opening dialogue and creating and supporting active collaborations. Returning to where I began this chapter, the responsibility to fix the leaky bucket and its associated system, and to be sure that all of the users receive high-quality nourishment, rests with all of us—practitioners, community members, and researchers alike. The educational system is no more than the sum of the intelligence and expertise of the people who make it up, and its care and upkeep can be improved and maintained if, and only if, we work strategically, urgently, and collaboratively toward these goals.

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